

Multispectral uncooled infrared enhanced-vision system for flight test

Carlo L. M. Tiana ^{a,b}, J. Richard Kerr ^b, Steven D. Harrah ^c

^a Aireyes, Inc., 1924 NE 38th Ave., Portland, OR 97212

^b Research Triangle Institute, Research Triangle Park, NC

^c NASA Langley Research Center, Hampton, VA

ABSTRACT.

The 1997 Final Report of the “White House Commission on Aviation Safety and Security”¹ challenged industrial and government concerns to reduce aviation accident rates by a factor of five within 10 years. In the report, the commission encourages NASA, FAA and others “to expand their cooperative efforts in aviation safety research and development”.

As a result of this publication, NASA has since undertaken a number of initiatives aimed at meeting the stated goal. Among these, the NASA Aviation Safety Program² was initiated to encourage and assist in the development of technologies for the improvement of aviation safety. Among the technologies being considered are certain sensor technologies that may enable commercial and general aviation pilots to “see to land” at night or in poor visibility conditions. Infrared sensors have potential applicability in this field, and this paper describes a system, based on such sensors, that is being deployed on the NASA Langley Research Center B757 ARIES research aircraft.

The system includes two infrared sensors operating in different spectral bands, and a visible-band color CCD camera for documentation purposes. The sensors are mounted in an aerodynamic package in a forward position on the underside of the aircraft. Support equipment in the aircraft cabin collects and processes all relevant sensor data. Display of sensor images is achieved in real time on the aircraft’s Head Up Display (HUD), or other display devices.

Keywords: Aviation Safety, Enhanced Vision System (EVS), Autonomous Landing Guidance (ALG), infrared, uncooled

1. SENSOR SELECTION.

The development of an infrared sensor based “Enhanced Vision System” for this effort followed a number of general guidelines. We were interested in deploying a system that represented the “state-of-the-technology” of uncooled microbolometer infrared systems. Infrared sensors can be categorized according to the means by which the imaging detector is temperature controlled; uncooled systems utilize a solid-state thermoelectric system to temperature-stabilize the detector element. Uncooled infrared systems typically exhibit somewhat reduced performance than cryo-cooled alternatives, but they were selected because of their lower cost of production and higher expected reliability. These parameters are important in the design of systems that are eventually aimed at the cost-sensitive commercial and general aviation markets. The higher reliability (as measured by greater Mean Time Between Failures – MTBF) of such systems is also of great importance to allow for system servicing at regularly scheduled aircraft maintenance intervals.

We constrained our search to off-the-shelf commercial sensors, due to budgetary and schedule considerations. Although it is conceivable that a custom-designed sensor might yield somewhat better performance, current high-performance infrared sensors are nonetheless representative of what this technology can deliver, for proof-of-concept purposes. The main advantages that could be obtained by designing a camera specifically for the purpose of airborne enhanced vision would be in the reduction of size of imaging electronics, and perhaps the integration of the forward optical surfaces (exposed to the airstream) with the overall design of the imaging elements. Neither optimization was required for the target installation platform (a research aircraft).

¹ See, for example, <http://www.avweb.com/other/gorerprpt.html>

² See, for example, <http://avsp.larc.nasa.gov/>

The authors' and general industry past experience with infrared systems for this purpose led us to select infrared cameras sensitive to two distinct spectral bands, usually referred to as "Short-Wave" (SWIR) and "Long-Wave" (LWIR), nominally 1-3 and 8-12 μm . The rationale behind this choice is that the former spectral range is optimally suited to the detection of typical airfield lighting systems³, while the latter systems are well suited to thermal imaging of environmental features such as runway markings, and possible flightpath obstacles (other aircraft, vehicles, stray wildlife, etc.).

A color, visible band CCD camera was also included in the sensor package for the purpose of documenting (approximately) the appearance of the scene to the naked eye.

The selected sensors' principal characteristics, as supplied by their manufacturers, are reported in Table 1.

	LWIR	SWIR	CCD
Pixel resolution (nominal)	320 Hx 240 V	320 Hx240 V	542 Hx497 V (RGB)
Optics Field Of View (FOV)	39° H x 29° V	34° H x 25° V	34° H x 25° V
Sensitivity metric	< 100 mK NETD ⁴	< 10 ¹⁰ ph/cm ² /sec NEI, <2LSB	4 lux
RS-170/NTSC analog video	Yes	Yes	Yes
Digital video output depth	14 bits	12 bits	No
Detector readout frame rate	60 Hz.	60 Hz. (typ.), 30 , 15 Hz. Avail.	NTSC standard, 30 Hz. interlaced
Detector type	Vanadium Oxide (VOx) on Silicon	Indium Gallium Arsenide (InGaAs)	N/A

Table 1 - Principal Sensor Characteristics

The field of view of the sensors was largely dictated by the commercial availability of optics. The aircraft HUD, one of the intended display devices for the sensor imagery, subtends a field of view of 32° H x 24° V. Since sensor imagery would have to be displayed on the HUD conformally, the required sensor FOV was slightly larger than this, to allow for boresighting of the sensors without introducing vignetting on the HUD. The closest choice for this parameter available among commercial focus-free athermalized optics for the LWIR was somewhat larger than would have been ideal. Available optics for the SWIR and CCD sensors were closer to the desired FOV values.

The infrared cameras' functions and various operator settings can be modified remotely by connecting a computer to standard serial ports on the cameras. This is a required feature to allow an operator in the aircraft cabin to control the function of the cameras mounted outside the aircraft.

3. ENVIRONMENTAL AND MECHANICAL CONSIDERATIONS.

The sensors selected for this EVS system were not designed to withstand the exposure they would undergo once installed on the exterior of an aircraft. These include temperatures nominally in the range -50°C (at altitude) to +40°C (on the ground), 35,000-ft. altitude, and moisture in various forms. Rather, typical applications of these systems are in the relatively well-controlled environments of laboratories or ground-based systems.

We therefore undertook to build a protective enclosure around the system electronics. The sensors and the main elements of the environmental enclosure are shown in Figure 1.

³ See, for example, J. R. Kerr et al., "Infrared-optical multisensor for autonomous landing guidance", Proceedings of SPIE, Vol. 2463, 4/1995.

⁴ NETD = Noise-Equivalent Temperature Difference; NEI = Noise Equivalent Irradiance; LSB = Least Significant Bit (system noise)

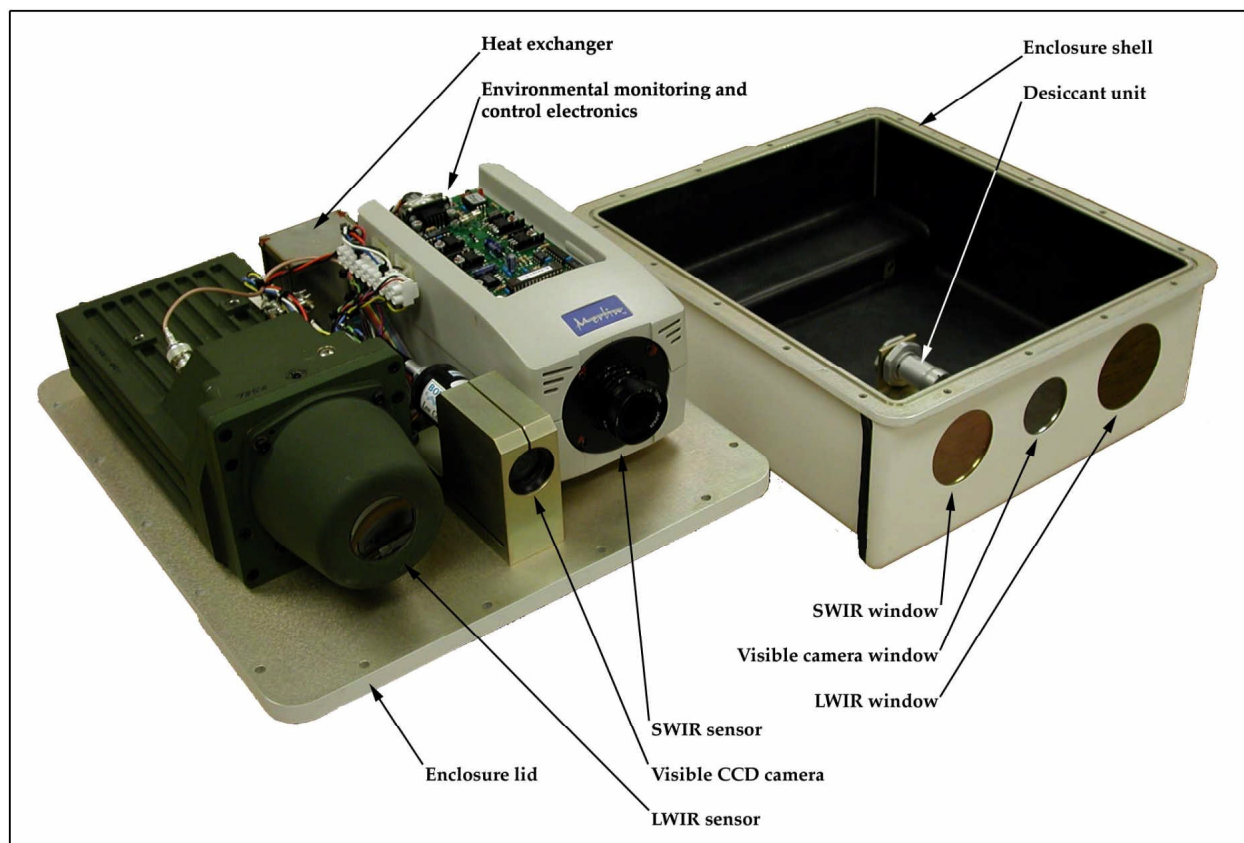


Figure 1 - System components.

The enclosure consists of a flat lid onto which all major system components are mounted, and a shell containing the optical windows and a desiccant capsule. The enclosure is hermetically sealed by means of an 'O' ring between the lid and the shell, and 'O' rings along the perimeter of each of the optical windows. All electrical signals and power to the system enter the enclosure through MIL-STD series hermetic connectors. Once the enclosure is assembled, it is filled with dry nitrogen through a purge and fill valve system. Nitrogen pressure is then set at 2 PSI above MSL, to ensure positive pressure at all times on the windows and connectors. This arrangement ensures that no moisture is trapped or can enter the sensor environment. The concern with eliminating trapped moisture is principally aimed at preventing its absorption on electronic components and PCBs, which can cause de-lamination and other damage upon repeated freeze cycles, as well as icing on optical surfaces. As a precautionary measure, a desiccant capsule is built into the enclosure.

Temperature and pressure inside the enclosure are monitored by means of custom-designed electronics. Both parameters are reported once per second via RS-422 connection to operators in the aircraft. Any pressure leakage can therefore be immediately detected. The environmental control electronics are also designed to stabilize the system temperature within a preset range (the conservative design range of the sensor units). This temperature control is achieved through a heat exchanger and a thermoelectric Peltier device. This device appears as a 1/8" thick and 2" square wafer with a pair of electrical leads. Application of an electrical current to this device causes one of its surfaces to heat up and the opposite surface to cool: 50 W of applied power can cause a temperature gradient of 60°C across the device. Nitrogen is circulated around the enclosure by means of stirring fans, through a set of fins on a heat exchanger. The Peltier device is sandwiched between the heat exchanger (internal to the enclosure) and a set of copper braids that attach to the aircraft. The aircraft acts as a heat reservoir, and the temperature at the point of attachment of the braids is guaranteed to not diverge substantially from about 20°C. Heat can therefore flow to and from the aircraft by means of this device, and the temperature inside the enclosure controlled to remain within acceptable operating and storage limits for the sensors.

The LWIR sensor is the largest unit in the system, and it is mounted rigidly to the lid. The SWIR and CCD sensors are mounted to the lid through certain custom-designed mechanisms to allow their optical boresighting to the LWIR camera. These boresighting mounts allow the SWIR and CCD sensors to be oriented relative to the LWIR sensor axis by $\pm 2^\circ$ vertically and $\pm 2^\circ$ horizontally. Once the sensors are optically boresighted to each other, they are locked down in position, and no further internal mechanical adjustments are required.

Installation of the sensor enclosure on the aircraft was achieved through substantial modification to a forward avionics bay access door, located on the underside of the aircraft, just in front of the nose gear bay, between STA 231 and STA 255 on the NASA Boeing 757 platform. This choice of location is not optimal due to its relative distance from the pilot's reference eyepoint, but was desirable as it minimized aircraft downtime for installation. A spare access door was procured and all modifications and fit-checks of the sensor enclosure mounting could be carried out without impact to the aircraft schedule.

The stock access door is a torsion box construction, consisting of some stiffening structure sandwiched between two aluminum membranes. The outer membrane normally constitutes part of the aircraft pressure vessel. The door is attached to the aircraft by means of two hinges that allow it to open inwards into the forward avionics bay. Modifications to this door were required to leave it operational, and to allow quick access to the avionics bay by maintenance personnel.

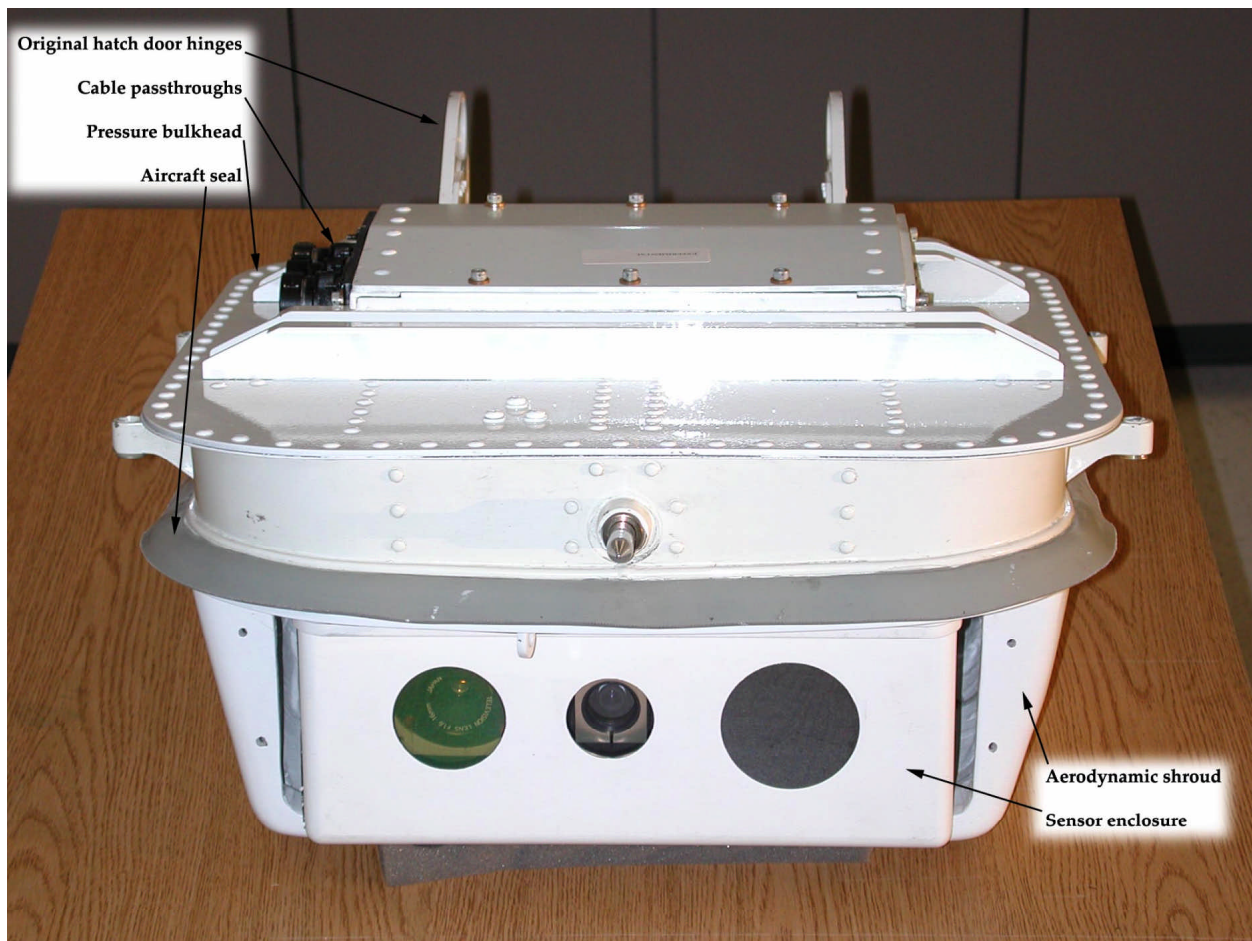


Figure 2 - Sensor system installed on aircraft hatch door.

The chosen design removed the outer (pressure vessel) surface of the door, and some of the internal structure, to carve out sufficient volume into which portions of the sensor enclosure could be recessed (for aerodynamic considerations). The upper door surface was then replaced with an Al plate, constituting the new pressure vessel plug. Substantial structural elements

were then added above the door to replace those removed from the original door design. An additional modification removed the standard door-opening handle from its original position in the center of the door, and replaced it with a custom mechanism to operate the door latch pin.

The sensor enclosure is then mounted to the modified door through a pair of hinges at the upper front corners of the enclosure and a bolt in the center rear. This arrangement was required to allow the sensor enclosure to be boresighted to the HUD's optical axis. By means of adjustment of the rear bolt, the whole enclosure can be adjusted $\pm 2^\circ$ in pitch from the nominal boresight position. The front hinges are attached using slotted plates that allow for azimuth adjustment of $\pm 2^\circ$ from nominal center.

Figure 2 shows the sensor enclosure mounted to the access door.

The enclosure itself was mounted onto the access door with an overall downward pitch bias designed to align the axis of the sensors to the optical axis of the HUD. The required downlook angle was calculated to be 10.5° with respect to the local aircraft surfaces at the access door location.

Finally, a fiberglass shroud was built, to enclose the sensor system and provide a cleaner aerodynamic profile to the installation. This shroud was mounted to the access door by means of a pair of tracks on either side, onto which it slides forward and is locked in position. Figure 3 shows the sensor enclosure mounted on the access door and the aerodynamic shroud on its tracks, part way into position for illustration purposes.



Figure 3 - Sensor system side view seen as would be installed on aircraft underside; aerodynamic shroud is partly retracted to expose sensor enclosure.

The access door modifications, as well as the enclosure construction and installation, were analyzed and tested by an FAA DER, who issued an overall Statement of Compliance with CFR 14 Part 25 for the finished assembly.

4. DATA COLLECTION SYSTEM.

The sensor enclosure is connected to an operator station in the aircraft cabin via a wire bundle approximately 140 ft. in length. This bundle carries all control and data lines between the enclosure and the control and data collection systems. A separate wire bundle carries power to the enclosure electronics.

A pair of PC-type computers at the operator station provide control, status monitoring and data collection support for the sensor enclosure. Each of the infrared sensors can be remotely operated via RS-232 / RS-422 serial connections. The environmental control electronics report temperature and pressure parameters over RS-422 to the computers.

The computers interface to image data from the sensors and process it as required by downstream customers. As currently deployed, the computers accept the analog video data streams from both infrared sensors and the CCD camera via three image processing subsystems (Matrox Genesis boards). The images are time-stamped with a common identifier unique to each frame, and stored to a RAID disk array of about 300 GB capacity. Under the assumption that a compressed RS-170 video frame of acceptable quality is about 300 KB in size, this is sufficient to store about 3 hours of video from each sensor. Practical limitations resulting from the distribution of disk capacity between the data acquisition computers, as well as the need to store other ancillary data and documentation, a more realistic estimate for the data storage capacity is about 1.5 hours from each sensor.

Current plans call for a future upgrade of the system to interface directly to the full-dynamic range, uncompressed digital data streams from the infrared sensors. The bandwidth of these streams is substantially higher (about 10 MB/s for each sensor), and recording duration will be proportionately reduced. Due to the distance between the sensor enclosure and the data collection computers, line drivers are required to transmit this high frequency signal.

The data collection computers also include interface cards to accept aircraft state parameter data from various ARINC 429 aircraft buses, and a master time signal from GPS. The full-rate 429 bus data is time-stamped and collected to disk, to allow correlation with the sensor image data.

5. CONCLUSION.

We have described design tradeoffs and construction of a dual-band uncooled infrared sensor system for installation on a NASA B757 testbed. This system and ancillary data collection station will be flight tested to evaluate the utility of infrared sensors for the improvement of aviation safety in various phases and conditions of flight.

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